Prospective life cycle assessment for biorefinery concept development

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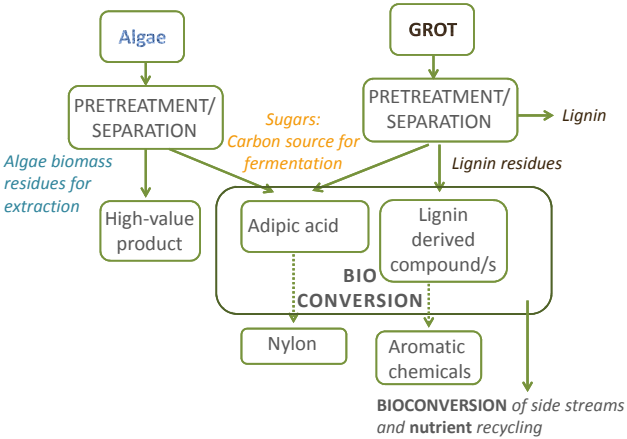
Outline

1. An example of prospective LCA in biorefinery development
2. A definition of prospective LCA
3. Use of scenarios in prospective LCA and a proposed scenario approach
4. Application of the proposed scenario approach
5. Conclusion

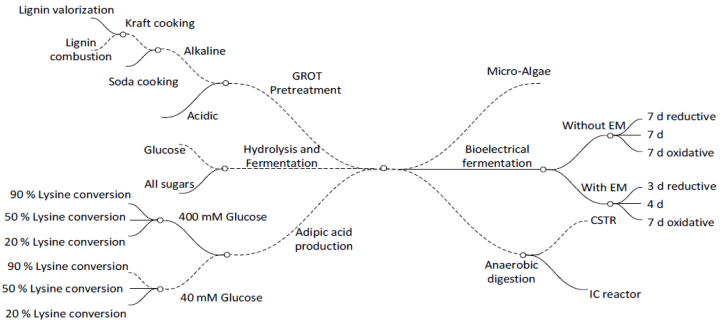
Bio-based production of adipic acid



- Biorefinery concept for the production of bulk and fine chemicals
- Bulk chemical → Adipic acid[1], lignin derivative
- Fine chemical → Lutein

[1] R. Aryapratama and M. Janssen. *J Clean Prod* 164 (2017), pp. 434–443.

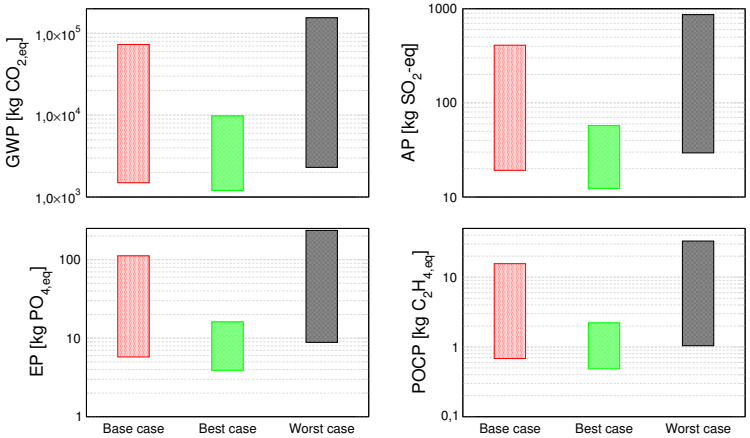
Construction of process alternatives



Twelve alternatives were constructed for the assessment

- Lysine conversion → 20 %, 50 % and 90 %
- Sugar concentration → 40 mM and 400 mM
- Sugar conversion → Only glucose, all sugars

Range of environmental impacts

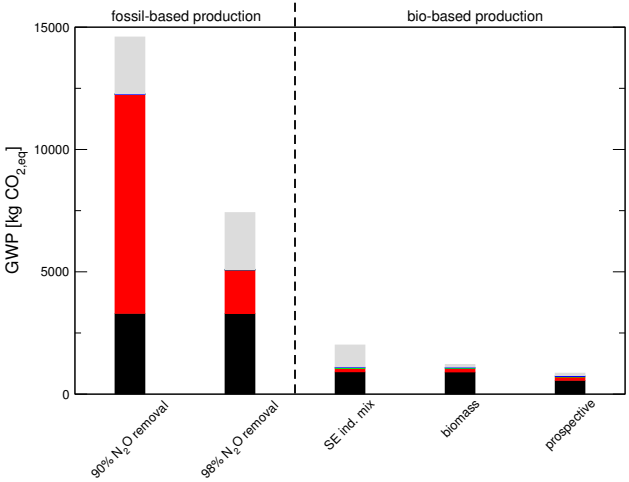


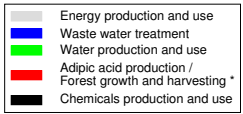
Variation due to

- Heating and cooling demand of the alternative
- Foreground energy system

Improvements in climate impact

From fossil-based to bio-based production





SE ind. mix: Swedish industrial energy mix (**foreground**)
biomass: Only biomass in energy mix (**foreground**)
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* Adipic acid production: fossil-based production
Forest growth and harvesting: bio-based production

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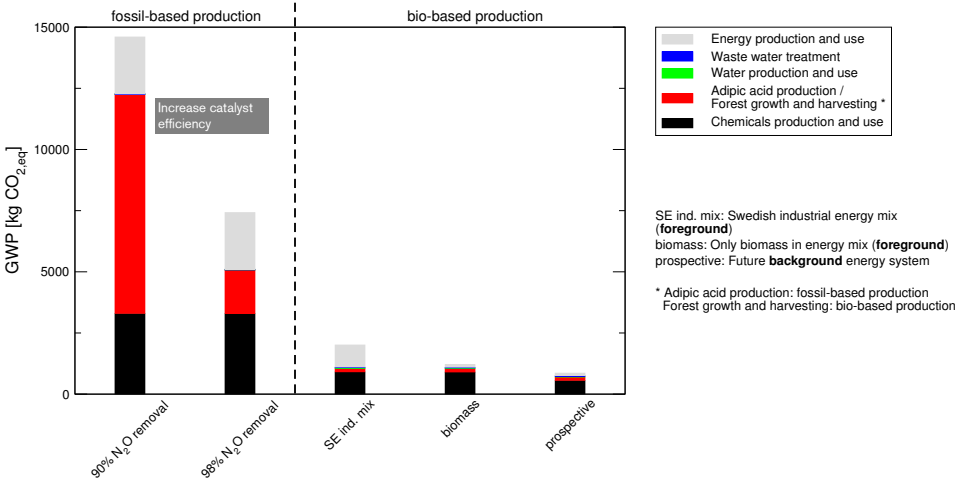

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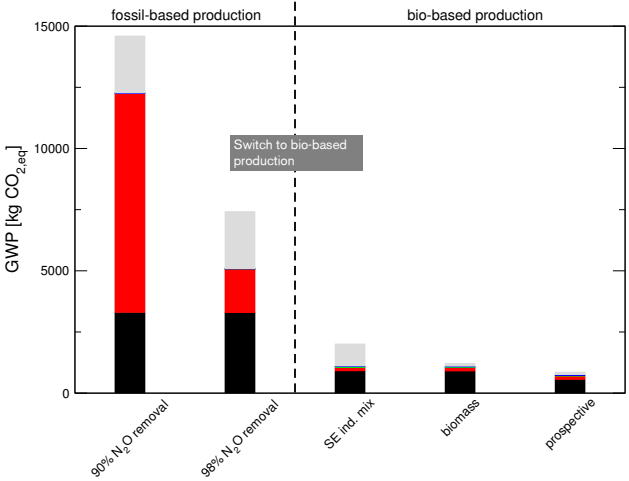

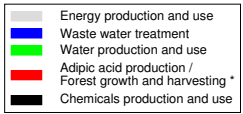

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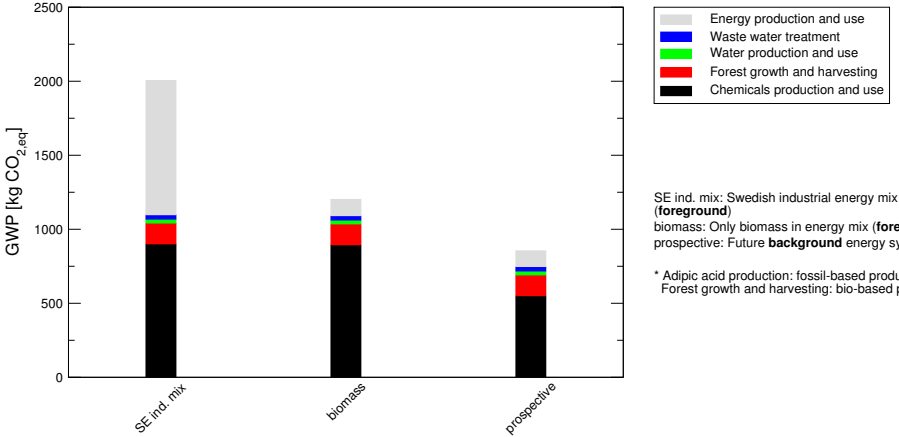

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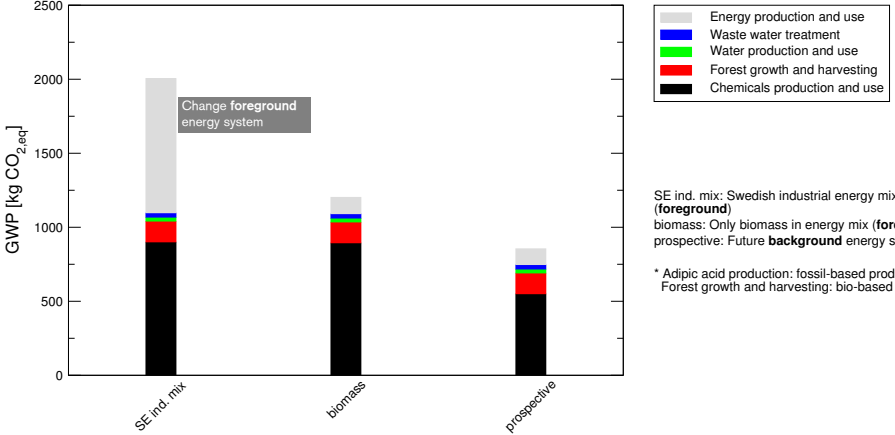

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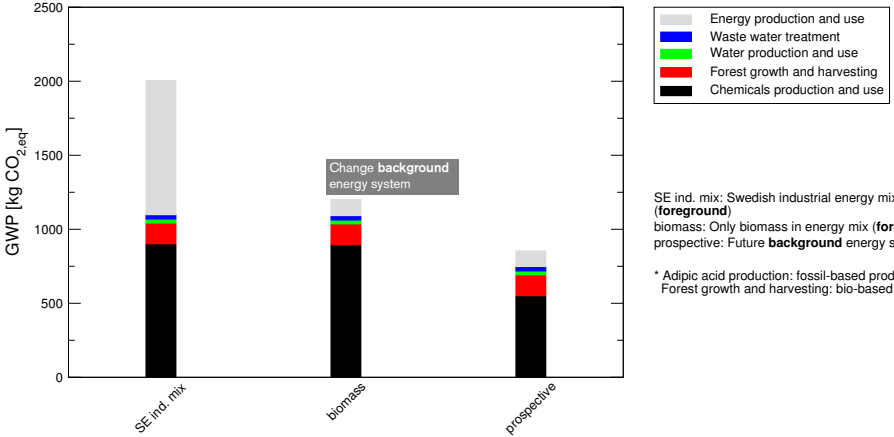

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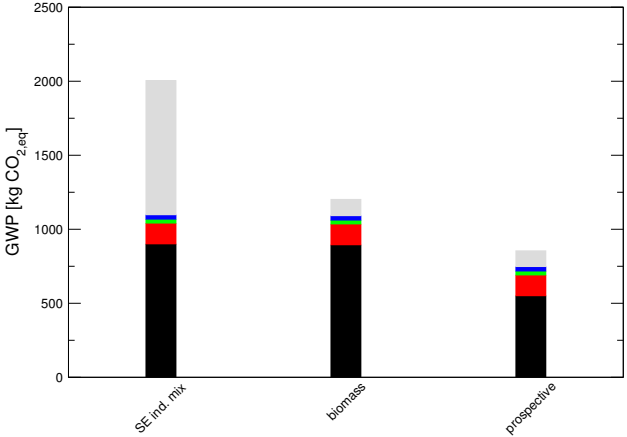

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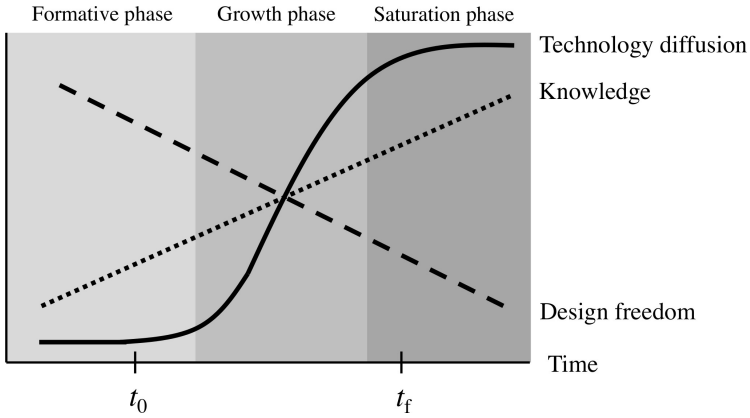
- Further improvements are possible
- Change in background energy system mainly affects chemicals production

Prospective LCA – a definition



Definition of pLCA[2] → "Studies of emerging technologies in early development stages, when there are still opportunities to use environmental guidance for major alterations"

[2] R. Arvidsson et al. *J Ind Ecol* 22 (2018), pp. 1286–1294.

Some recommendations for doing prospective LCA[2]

- Technology alternatives
  1. Focus on a specific function provided by different technologies
  2. Cradle-to-gate studies of technologies with many potential future uses
  3. Focus on a specific technology to illustrate a relevant point for the future

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  - Predictive scenarios → Based on forecasts or trends
  - Scenario ranges → Illustrate potential environmental impact

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- Foreground system data
  - Predictive scenarios → Based on forecasts or trends
  - Scenario ranges → Illustrate potential environmental impact
- Background system
  - Avoid mismatch between foreground and background systems
  - Use scenarios as for the foreground system

[2] R. Arvidsson et al. *J Ind Ecol* 22 (2018), pp. 1286–1294.

A very short literature review on scenarios in (prospective) LCA

- The use of scenarios in LCA is not something new[3]
- Recent literature on pLCA highlights the use of scenarios[4,5,6]

[3] B. P. Weidema et al. Ed. by G. Rebitzer and T. Ekvall. Pensacola: SETAC Press, 2004.
[4] J. A. Bergerson et al. *J Ind Ecol* 24.1 (2020), pp. 11–25.
[5] G. Thomassen et al. *Green Chem* 21.18 (2019), pp. 4868–4886.
[6] N. Thonemann, A. Schulte, and D. Maga. *Sustainability* 12.3 (2020).
[7] M. Spielmann et al. *Int J Life Cycle Assess* 10.5 (2005), pp. 325–335.

A very short literature review on scenarios in (prospective) LCA

- The use of scenarios in LCA is not something new[3]
- Recent literature on pLCA highlights the use of scenarios[4,5,6]
- Guidance on how to design and develop scenarios in pLCA does not seem to be abundant
  - Only example is by Spielmann et al (2005)[7]
  - Method for quantification of scenarios at the unit process level was presented

[3] B. P. Weidema et al. Ed. by G. Rebitzer and T. Ekvall. Pensacola: SETAC Press, 2004.
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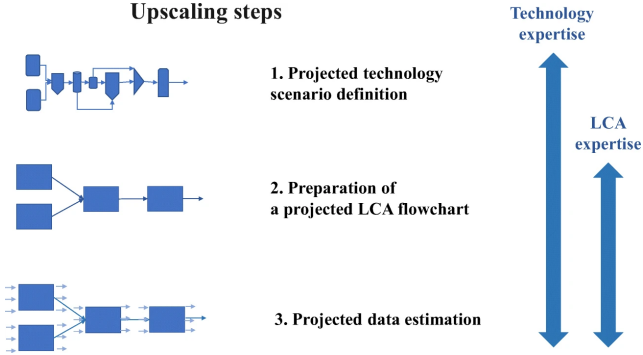
Quantification of scenarios

Foreground system[8]

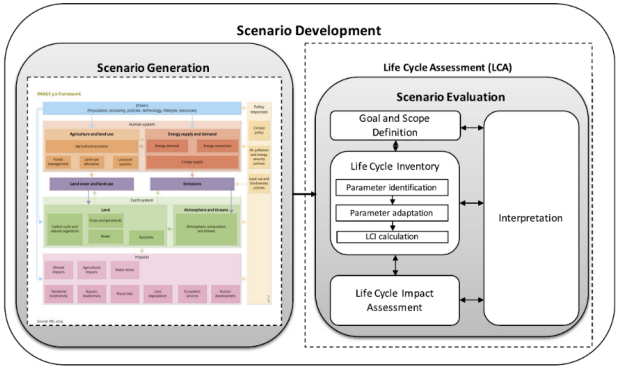


- Technology experts should be involved; technology scenario development should be reported
- LCA experts define full flowchart; report how technology scenarios have been translated
- Cooperation between LCA and technology experts

[8] N. Tsoy et al. *Int J Life Cycle Assess* 25.9 (2020), pp. 1680–1692.

Quantification of scenarios

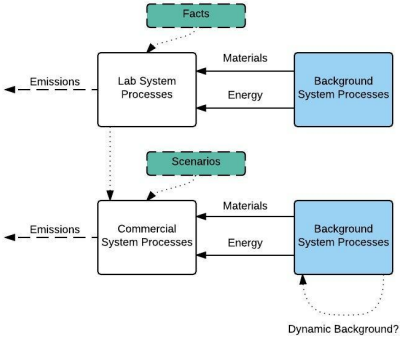
Background system[9]



- Coupling of LCI energy scenarios and Integrated Assessment Models (IAMs)
- Integration of future scenarios from the IMAGE model into ecoinvent

[9] A. Mendoza Beltran et al. *J Ind Ecol* 24.1 (2020), pp. 64–79.

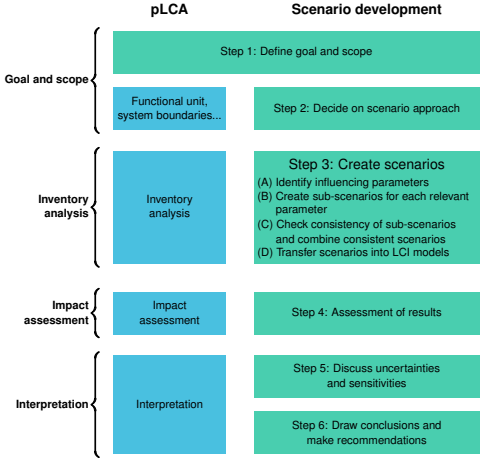
Scenario types and methods



- Types[10]
  - Predictive → How the future will develop
  - Explorative → How the future could develop
  - Normative → How the future should develop
- Methods
  - General Morphological Analysis[11]
  - Scenario Planning[12]
  - Formative Scenario Analysis[13]

[10] L. Börjeson et al. *Futures* 38.7 (2006), pp. 723–739.
[11] T. Ritchey. *16th Euro conference on Operational Analysis*. 1998.
[12] P. J. H. Schoemaker. *Sloan Manage Rev* 36.2 (1995), pp. 25–40.
[13] R. W. Scholz and O. Tietje. Thousand Oaks, California: Sage Publications, Inc., 2002.

A proposed scenario approach I[14]



- Scenario development depends strongly on the overall goal and scope of the LCA
- Scenarios may be predictive, explorative or normative
- **Scenarios need to be created for the foreground and the background systems**
- Assessment for each of the scenarios is done
- Parameter uncertainty is analyzed
- Conclusion are drawn and recommendations are made

[14] Manuscript in preparation - Langkau et al

A proposed scenario approach II[14]

1. Identify influencing parameters → Which parameters influence the answers to the research question?
2. Create sub-scenarios for each relevant parameter → Which developments are possible for each relevant parameter?
3. Check consistency of sub-scenarios and combine consistent scenarios → Which developments of different parameters are consistent with each other?
4. Transfer scenarios into LCI models → Which results follow from the made assumptions?

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1. Identify influencing parameters → Which parameters influence the answers to the research question?
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   - Several plausible developments of each relevant parameter
3. Check consistency of sub-scenarios and combine consistent scenarios → Which developments of different parameters are consistent with each other?
   - Many formally possible combinations of sub-scenarios → Find most plausible ones
4. Transfer scenarios into LCI models → Which results follow from the made assumptions?

[14] Manuscript in preparation - Langkau et al

Can carbon fiber composites have a lower environmental impact than fiberglass?[16]

- Lightweighting of vehicles $\rightarrow$ Reduction of fuel consumption during use
- Use of composites
  - Glass fiber reinforced polymers, GFRP (also known as fiberglass)
  - Carbon fiber reinforced polymers, CFRP (also known as carbon fiber composites)

[15] F. Hermansson, M. Janssen, and M. Svanström. *J Clean Prod* 223 (2019), pp. 946–956.
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- Shift from GFRP to CFRP may increase the climate impact and energy use[15]
  - Due to the energy intensive carbon fiber production process
  - Carbon fiber production process generally contributes the most to the CFRP life cycle environmental impact

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  - Carbon fiber production process generally contributes the most to the CFRP life cycle environmental impact
- A pair of car mirror brackets are the subject of study
  - To assess the potential impacts of the future use of CFRP and GFRP to explore if and under what conditions CFRP can outcompete GFRP environmentally

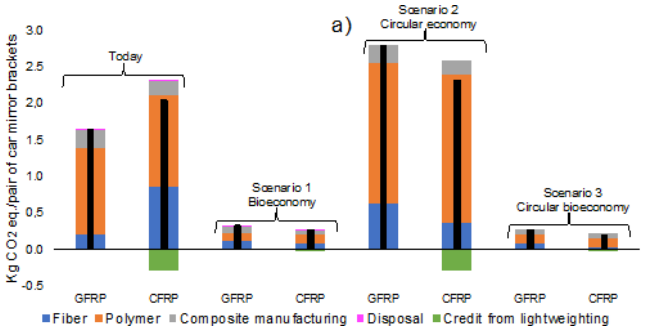
[15] F. Hermansson, M. Janssen, and M. Svanström. *J Clean Prod* 223 (2019), pp. 946–956.

[16] F. Hermansson et al. *Resourc Cons Recycl* (2021), under review.

The constructed future scenarios

- Scenario parameters related to the foreground or background system were established
- Causal loop diagram was made to map how these parameters interrelate
- Consistency check of the possible scenarios was done in order to reduce their number
- Three different scenarios were constructed
  1. Future with a strong focus on the bioeconomy – Only lignin-based carbon fibres, sent to landfill, used in a BEV
  2. Future with a strong focus on a circular economy – Only fossil-based carbon fibres, fully recycled, used in an ICEV
  3. Future with a strong focus on a circular bioeconomy – Only lignin-based carbon fibres, fully recycled, used in a BEV

Climate impact results for the three scenarios



- Today → Carbon fibre production is detrimental
- Bioeconomy scenario → In a carbon-lean energy system, reduction in energy use has less influence
- Circular economy scenario → Lower climate impact for CFRP thanks to recycling
- Circular bioeconomy scenario → Situation is similar to the bioeconomy scenario

Conclusions

- LCA can be used for assessing emerging biorefinery technologies and for guiding early technology development → Prospective LCA
- An approach to scenario construction for prospective LCA was proposed
  - Integrated in the goal & scope definition and inventory analysis steps of the LCA
  - Different scenario types can be constructed
  - Consistent scenarios are obtained

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  - Integrated in the goal & scope definition and inventory analysis steps of the LCA
  - Different scenario types can be constructed
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- Future work
  - Development of future scenarios → Integration of scale-up approaches in LCA, further refinement of scenario development
  - Impact assessment → New types of environmental problems, selection of impact categories

Acknowledgement

- Co-authors
- Project colleagues in the MIN-TEA project
  - Sabine Langkau – Fraunhofer Institute for Systems and Innovation Research ISI, Germany
  - Bernhard Steubing – Institute of Environmental Sciences (CML), Leiden University, The Netherlands
  - Chris Mutel – Paul Scherrer Institute (PSI), Switzerland

THANK YOU

Any questions?